RESEARCH DEPARTMENT

The reflection of sound from television scenery flats

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THE BRITISH BROADCASTING CORPORATION
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A.N. Burd, B.Sc., A.Inst.P.

Head of Research and Development

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SUMMARY

Measurements of the sound-pressure reflection coefficients of typical scenery-flat materials have been made. Substantial agreement has been found between two methods of measurement with regard to the order in which they rank the reflective properties of typical materials. The report ends with some comments relating to the sound insulation and acoustics of sets with open sides and tops, which are relevant to the choice of materials for flats.

1. INTRODUCTION

The selection of scenery flats for use in the construction of a particular set is at present based largely on availability. Certain types of material have been found to be particularly suited to the representation of some surfaces; for example, the surface irregularity of brickwork or stonework can be well simulated by flats made from fibreglass and resin whose surface can be moulded.

On some occasions, the acoustical qualities of the materials used in the construction of a flat are of considerable importance and should be taken into account when the set is being designed; this will obviously be true for orchestral and operatic productions.

Acoustical information concerning the reflective properties of materials used for scenery flats has, however, been almost non-existent and selection of materials has, therefore, relied on the past experience of those involved. In order to provide objective data on which selection could be based, measurements of the acoustic properties of typical flat materials have been made. This report outlines the results of the measurements and includes some discussion of other related topics.

2. DESCRIPTION OF MEASUREMENTS

2.1. General

Nine typical examples of television scenery flat were supplied for test and measurements were carried out on these at frequencies between 500 and 8000 Hz. Subsequently, the range of measurements was extended down to 125 Hz for four representative flats from the above nine.

Five of the flats consisted, basically, of 3 mm plywood fixed to a timber frame, although the surface treatment in each case was different. The surfaces were of thin aluminium sheet, plastics sheet, hessian, painted wallpaper and a washable wallpaper. Three of the flats were made, respectively, from fibreglass (approximately 2 mm thick and having the surface appearance of a brick wall), painted canvas and expanded polystyrene. The remaining flat consisted of a black fabric drape. The dimensions of the majority of the flats were 3 m x 1·2 m; in all cases the smaller dimension was at least 1·2 m.

In order to eliminate spurious reflections from the walls of the enclosure, the tests were carried out in the larger of the two free-field rooms at Research Department. The inside dimensions of this room are 6·1 m x 4·9 m x 3 m and the amplitude reflection coefficient of the walls is less than 10% at all frequencies above 50 Hz; above 125 Hz the reflection coefficient is less than 4%.

In order to facilitate the movement of the heavy and bulky flats in and out of the room, it was necessary to cover approximately half the floor area of the room with wire-mesh flooring panels. Protective stanchions and guard ropes were erected while moving the flats and, although these were removed for measurements, it was not considered necessary to remove the flooring panels. Measurements confirmed that the reflections in the absence of a flat were small compared with those from the surface of the flat.

Two techniques of measurement were used and these are described in the following sub-sections.

2.2. Correlation Measurements

It has been shown[1] that a cross-correlation technique may be used in measurements of acoustical transmission or reflection in order to separate signals on the basis of their time of arrival; an analogue correlator suitable for acoustic measurements has been constructed in Research Department. The correlator determines, as a continuous function of a variable delay time, the cross-correlation coefficient between an input white-noise signal and the output of a microphone in the sound field of a loudspeaker radiating the white noise. A maximum in the cross-correlation function is found for each value of delay time corresponding to the time of transit of the acoustic signal from loudspeaker to microphone.

The microphone and loudspeaker are situated on a line normal to the experimental surface, with the microphone at a certain distance, say d, from the surface and the loudspeaker at a greater distance. Peaks will be found in the cross-correlation function corresponding to the direct signal from the loudspeaker and, after a further delay time $2d/c$, corresponding to a signal reflected from the surface (where c is the velocity of sound in air). The difference in the heights of these two peaks will be due, in part, to divergence of the sound wave and, in part, to loss of energy on reflection from the surface.

It should be possible to correct for the loss of level due to divergence of the sound wave since this loss can be determined from a measurement made in the absence of the reflecting surface and with the microphone moved a distance $2d$ beyond its normal position. This correction having been taken into account, the remaining part of the difference should indicate the reduction of level of the signal on reflection from the surfaces of the flat.

The peaks in the cross-correlation function are determined by the signal level from the microphone, since the average level of the white noise fed to the loudspeaker is maintained constant. Thus the derived reflection coefficient is the ratio of reflected pressure to incident pressure and not the ratio of reflected energy to incident energy which is sometimes given as the definition of the term.

In order to determine the variation of the reflection coefficient with frequency, octave band-pass filters are introduced into the analysis circuits. These frequency limitations give rise to damped oscillatory forms of cross-correlation function, the period of oscillation corresponding to the centre frequency of the filter in use. It is necessary that the peaks arising from the direct and reflected sound be separable and, for octave bands, this requires that the path difference be twice the wavelength of sound at the lowest frequency of each band.

2.3. Tone-Burst Measurements

A method of measurement using short bursts of tone[2] has been shown to be equivalent to that based upon cross-correlation. The separation between direct and reflected sound is carried out on a time basis and, for a given length of burst, there exists a minimum spacing between microphone and scenery flat to enable this separation to be made.

In the tests, a 'tone pulser' produced a train of tone bursts each of 4 ms duration and this train was radiated from a loudspeaker situated in one corner of a free-field room. The reflecting surface of the flat was placed approximately 4·2 m from the loudspeaker and an omni-directional microphone hung between the loudspeaker and the flat. The line joining the microphone and loudspeaker was normal to the surface of the flat.

The microphone output, after suitable amplification, was filtered to remove extraneous noise by means of one of a set of octave band-pass filters having centre frequencies spaced at half-octave intervals, and the filter output was displayed on an oscilloscope.

The frequency of the oscillator in the tone-burst generator was set at the centre frequency of the band-pass filter in use and the microphone gain first adjusted so that the direct burst was displayed with a convenient height. The change in gain necessary to bring the display of the second (reflected burst) to this same height was then noted. This procedure was followed for each of the band-pass filters, whose centre frequencies covered the range 500 to 8000 Hz.

As discussed in the section above on correlation measurements, the difference in amplitude between the direct and reflected bursts arises in part from reflection at the surface but additionally by divergence of the sound wave. A similar measurement to that carried out with the correlator was made for the pulse measurements. However, owing to the greater distances used in the pulse measurements, the microphone, when moved beyond the position of the scenery flat, was brought to the corner of the free-field room. It has been shown that, for a microphone in the corner of the free-field room, some excess attenuation of sound occurs at the lower frequencies and this may account, in part, for the anomalous result that for some materials at some frequencies the correction for distance alone is greater than the measured attenuation. (For the reasons given below, detailed reflection coefficients obtained by this method are not quoted here.) The excess attenuation was found at 500 and 700 Hz for most materials; additionally, three of the flats showed these anomalous results at most frequencies. For one of them, the aluminium-faced plywood, this effect was undoubtedly due to a tendency of the sheet to bow slightly and produce a focusing effect in the region of the microphone. Some degree of focusing may also have existed in the other two cases.

Measurements at some frequencies were exceedingly difficult due to severe distortion of the burst envelope which was highly variable with frequency; a change of a few hertz in the frequency of the tone was usually sufficient to restore a normal flat-topped envelope. In retrospect it would probably have been preferable for these measurements to have been done with, say, bursts of one-third octave bands of noise.

It was not thought possible to derive absolute figures of the amplitude reflection coefficient as the results of the two methods of measurement differed widely and the figures were therefore used to place the various surfaces in rank order in relation to their reflective properties. The results obtained in this way are compared with those obtained by correlation.

3. RESULTS OF MEASUREMENTS

The correlation results are given in full, in Fig. 1, for the four materials for which the full frequency range was covered; in addition Table 1 shows the correlation results for all the materials in order of increasing average reflection coefficient.

The results of tone-burst measurements are expressed only in order of increasing reflection coefficient on the basis of the mean of the measured values; this rank order is compared in Section 3.2 with that found by correlation.

3.1. Experimental Details and Results

The correlation measurements within the limited frequency range 500 to 8000 Hz were made

TABLE 1

Pressure Reflection Coefficients of Scenery-Flat Materials
(Correlation Method)

Material	Frequency, Hz													Mean Value (700-8000 Hz)
	125	175	250	350	500	700	1000	1400	2000	2800	4000	5600	8000	
1 Black fabric	45	20	20	20	20	50	38	21	28	33	31	30	23	32
2 Painted canvas	70	20	22	16	13	63	75	53	56	53	48	67	48	58
3 Wallpaper on plywood	-	-	-	-	-	63	47	60	63	67	48	67	73	61
4 Plastics sheet on plywood	-	-	-	-	-	79	75	67	63	75	61	75	65	70
5 Colourboard (hardboard)	-	-	-	-	-	89	60	75	63	53	62	94	92	73
6 Wallpaper on hessian on plywood	63	50	50	35	32	71	67	67	89	75	97	106	92	83
7 Expanded polystyrene	-	-	-	-	-	100	67	53	71	75	77	168	103	88
8 Aluminium-faced plywood	-	-	-	-	-	126	75	67	89	94	108	133	162	94
9 Fibreglass on timber frame	88	56	71	56	44	79	75	67	100	119	122	188	182	116

with a loudspeaker-to-reflector distance of 1·2m and a microphone-to-reflector distance of 0·9m. These spacings were sufficient to resolve fully the correlation peaks at 500Hz for octave bandwidths of noise. In order to extend the measurements to include an octave centred on 125Hz the microphone-to-reflector distance was increased to 3·55m and the loudspeaker moved to a correspondingly greater distance. The results of the correlation measurements were derived as explained in Section 2.2.

The accuracy achievable with correlation measurements proved to be somewhat disappointing. The long-term repeatability of a given measurement was only of the order of ± 1dB and since the difference of two terms is involved the final accuracy of the results is probably no better than ± 2dB (i.e. ± 23% say).

The use of a finite size of reflector will influence the results obtained and the frequency below which a serious reduction of reflected energy occurs may be derived by reference to Fresnel diffraction theory; it is additionally possible to calculate the amplitude fluctuations which will occur, at a point on the axis, at higher frequencies. An estimate has also been made of the possible results of curvature of the reflecting plane.

In the case of the correlation measurements at high frequencies, in which the loudspeaker and microphone were close to the reflector, the finite size of the reflector should give rise, within the frequency range of interest (500Hz and above), to a series of fluctuations amounting to a fall of 2·4dB at 820Hz, a rise of 1·5dB at 1320Hz and a series of variations of gradually decreasing amplitude at higher frequencies, all relative to the value for an infinite plane reflector. The significance of these corrections depends on the spectrum of the reflected signal within the octave band of measurement.

When the distances of the loudspeaker and microphone from the reflector are increased to extend the range down to 125Hz, the finite size of the reflector becomes of greater significance. Thus at 125Hz the limited size of the reflector alone leads to a loss of amplitude of 6dB in the reflected signal. The correction decreases to zero at 500Hz but fluctuations will arise in the results, as described above. The results in Table 1 and Fig. 1 have been corrected to allow for this effect. It seems probable that the rise in reflection coefficient at 125Hz may be due to the effect of an inadequate integrating time in the correlator.

The effect of cylindrical curvature of the surface is to concentrate the reflected energy on the axis. In the limiting case where the microphone is at the axis of curvature of the surface, reflections from all over the surface arrive in phase. Calculations indicate that, for this limiting case, a reflection coefficient of 25% coupled with the focusing effect would be sufficient to give an indicated reflection coefficient of 122% at 4kHz or 180% at 8kHz. Since it was obvious that, for the close correlation measurements, the axis of curvature of the surface lay far behind the microphone position the effect should not have been as severe as the above example would indicate; however, Table 1 includes results which suggest that an actual 100% reflection could well give an indicated 180% for some curvature of the surface.

As explained above the tone-burst results are not considered in detail but the rank order of the average reflection coefficients is shown in Table 2 compared with the order found by correlation. Since the tone-burst measurements were carried out only at frequencies of 500Hz and above, the effect of the finite size of the reflector is negligible and no correction to the results is necessary.

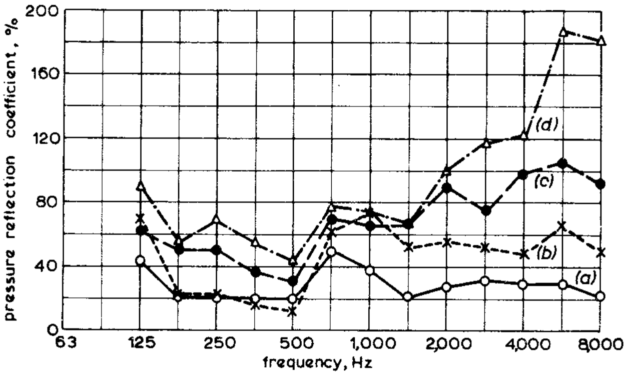

Fig. 1 - Pressure reflection coefficients of scenery-flat materials; correlation measurements

(*a*) Black fabric
(*b*) Painted canvas
(*c*) Wallpaper on hessian on plywood
(*d*) Fibreglass on timber frame

3.2. Statistical Analysis and Discussion

It is apparent, from Table 2, that complete agreement does not exist between the reflection coefficients obtained by correlation and by tone-burst measurements. However, some measure of agreement does exist and this is confirmed by calculating Spearman's Rank Correlation Coefficient for the two sets of results (see for example Reference 3). The rank correlation coefficient has been designed so that when the two rankings are identical the coefficient has a value +1 while for complete disagreement the coefficient has a value −1.

TABLE 2

Scenery-Flat Materials in Rank Order of Lack of Reflection

Material	Rank order from correlation (as above)	Rank order from tone bursts	Overall rank order
Black fabric	1	1	1
Painted canvas	2	4	2 =
Wallpaper on plywood	3	3	2 =
Plastics sheet on plywood	4	6	5
Colourboard (hardboard)	5	7	6 =
Wallpaper on hessian on plywood	6	2	4
Expanded polystyrene	7	5	6 =
Aluminium-faced plywood	8	9	8 =
Fibreglass on timber frame	9	8	8 =

For the above sets of results the Spearman's Coefficient has a value of +0·69, indicating a degree of agreement, and a test of significance by Student's 't' method[4] shows that the agreement is probably significant at the 5% level.

Since a measure of agreement exists between the two sets of results available it seemed worth while to add together the two rank orders found from the correlation and tone-burst results to determine an overall rank order, as has been done in column 3 of Table 2. (The symbol '=' implies that two, or more, materials show the same overall value of rank order.) These overall values may provide a reasonable guide to the use of materials for particular acoustic requirements.

It is apparent, and not unexpected, that a fabric has a low acoustic reflection factor. Its suitability for the construction of sets is however limited largely to cycloramata and occasional, obviously fabric, back drops. When the fabric is of painted canvas stretched over a wooden framework, the reflection coefficient is raised at middle and high frequencies to a value very similar to that of plywood-backed materials. At low frequencies the results are not significantly different from those for the fabric sample.

The flats made from plywood or hardboard form a large class of fairly efficient reflecting materials whose behaviour at the high frequencies may be affected slightly by the surface finish. The experimental measurements have not proved sufficiently accurate to enable conclusions to be drawn on these detailed differences.

The most efficient acoustic reflectors proved to be the fibreglass flats and, particularly because of its hard surface finish, the aluminium-faced plywood.

4. OTHER FACTORS OF INTEREST

Several other factors may be relevant in the choice of materials for a particular purpose. Acoustic energy which is incident on the scenery flat will be part reflected, part transmitted and the remainder absorbed by the material. Transmission and absorption are discussed in the next two sections.

Depending on the reflecting properties of the materials used in the construction of a set, it is possible that pressure distributions may arise which result in undesired effects; two simple forms of such a distribution are pointed out in Section 4.3.

4.1. Transmission Through Flats

The acoustic separation between two sets arises from acoustic shielding due to the flats and is limited normally by the fact that each set is not totally enclosed. If the shortest path between the sets is over the top of the flats, which we may take to be 3m high, and if the source and receiver are each at a height of 1m and a distance from the common barrier of 2m, then the maximum possible isolation between the areas will be of the order of 20dB at 500Hz. The isolation will increase with frequency but a limiting value of 25dB has been found in practice.

These figures are based on the assumption that there is no appreciable transmission through the material of the flats. With a flat material of low transmission loss the level difference will be determined by this loss instead of by the configuration of the sets.

Fig. 2 shows values of the sound reduction through samples of four of the flat materials as determined by a correlation method described elsewhere[1]. It will be seen that the isolation between sets constructed of fabric or painted canvas, curves (*a*) and (*b*), would be limited by the transmission through the flats, whereas the isolation between plywood and fibreglass sets (curves (*c*) and (*d*)) would be determined by the 25dB limit imposed by the open configuration.

A television studio is normally designed to be a dead acoustic environment since this leads to the most practical compromise in its use for speech or music. Energy which is transmitted through or over the walls of a set is therefore largely absorbed at the surface of the studio.

4.2. Absorption by Flats

Acoustic absorption is the remaining factor which influences the distribution of acoustic energy within the confines of a set in a television studio. Energy which is not reflected or transmitted will be dissipated in the material of which the flat is made. With the exception of draped fabrics, the absorption is small. The results of measurements on painted canvas and hessian-faced plywood are shown in Fig. 3; these results are random-incidence absorption coefficients obtained from a reverberation room measurement.

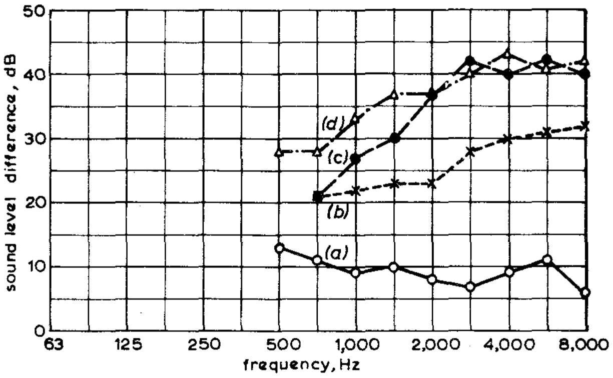

Fig. 2 - Sound reduction through scenery-flat materials; correlation measurements

(*a*) Black fabric
(*b*) Painted canvas
(*c*) Plywood
(*d*) Fibreglass

The effect of fabric coverings on the sound absorption of porous materials has been reported previously[5] and this report contains results determined on fabrics draped or stretched over a shallow air-space. The increase of depth of the air-space behind a material normally improves the low-frequency absorption and so the draping of fabrics in a television studio should lead to efficient absorption. Typical results for heavy velour might be expected to rise to 80% absorption by 500Hz and to maintain this absorption to high frequencies. Lighter fabrics show results depending more on the resistance of the fabric to flow of air but will frequently achieve 50% absorption or greater at middle and high frequencies.

Although the absorption of most scenery-flat materials is low, it will generally equal or exceed that given by the structures it is intended to portray. However, the acoustic environment within a room will seldom be fully portrayed since it is not common practice to construct a set having four walls and a ceiling. The open surfaces tend to be highly absorbent due to the dead acoustics of the surrounding television studio.

4.3. Pressure Distribution Within a Set

If a pair of reflecting surfaces are constructed opposite and parallel to each other, an acoustic standing wave may arise between the surfaces. This is audible on an impulsive sound as a periodic repetition of the sound, commonly known as a flutter echo. Ideal conditions for the audibility of such echoes will exist where two pairs of the surfaces of an enclosure absorb while the remaining two reflect. These conditions will be found in the normal set where one wall and the ceiling are open areas and therefore absorbing. The side walls may constitute a pair of reflecting surfaces and therefore produce an audible flutter. For a given surface area the repetition rate of the flutters falls as the distance between the surfaces increases and hence, for a given loss of energy at each reflection, the duration of the echo increases. As the surface area of the reflecting surfaces is decreased the duration of the flutter falls, particularly at the low frequencies.

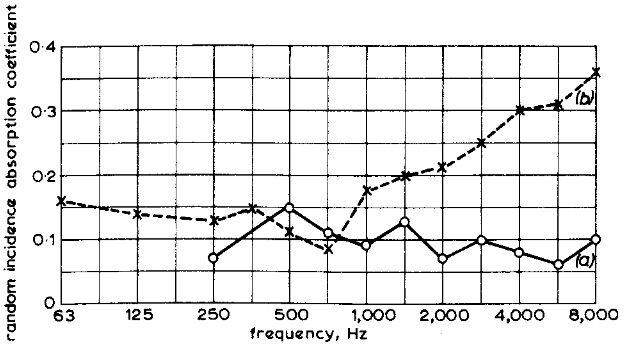

Fig. 3 - Absorption coefficients of scenery-flat materials; reverberation room measurement
(*a*) Painted canvas
(*b*) Hessian-faced plywood

The means for the elimination of flutter echoes have been studied by Krauth and Bücklein[6] in a series of model experiments. The introduction of some form of barrier between the surfaces or the breaking up of the surface with, say, hemi-cylindrical diffusers are efficient means of reducing the duration of flutters. However, the introduction of absorption on the surface or the splaying of one surface relative to the other is more usual. It is shown that an absorption coefficient of 10 to 20% is adequate to reduce the duration of most flutters to below one second; thus most scenery-flat materials provide sufficient absorption to avoid severe flutter effects. If a flutter echo is apparent in a particular case, then splaying one wall relative to the other by perhaps 5° should provide adequate reduction.

A microphone close to a reflecting surface will lie in a region where pressure doubling occurs. For a given distance from a surface the effect will only be noticeable at low frequencies, where the distance is smaller than the wavelength of sound, and the programme material therefore has a low-frequency emphasis which may be noticeable. While this would be heard by a listener in this position it is quite common for camera and microphone to be in very different positions and the acoustic and visual scenes can therefore be at variance.

5. CONCLUSIONS

The measurement of the reflection coefficient of scenery-flat materials by two techniques has been described. The agreement between the two sets of results is disappointing but a rank order of reflecting properties has been determined for the materials supplied. This order correlates well with expectations; the lighter materials reflect relatively inefficiently, those flats having a plywood backing reflect more efficiently and differences between various surface finishes affect the reflection properties at high frequencies only. A heavy fibreglass flat and an aluminium-faced plywood proved to be very efficient reflectors.

Various other properties of scenery flats or the sets constructed from them, which arise from the acoustic qualities of the materials, have been discussed briefly. The aim has been to assist in the selection of the correct material for a particular application.

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